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GEO-HYS

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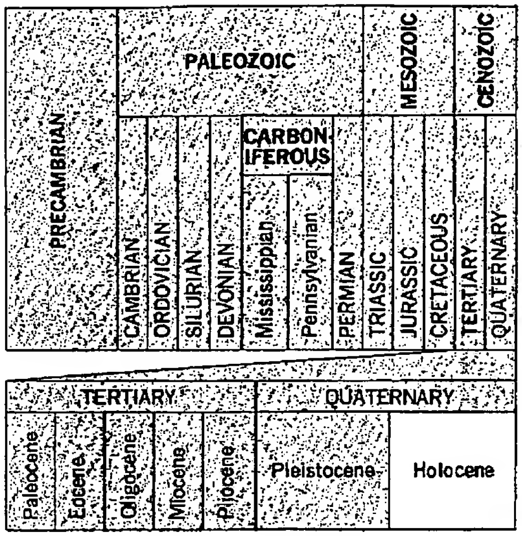


high latitudes was progressive, the boundary between the Holocene Epoch and the older Pleistocene Epoch has been set variously around a generally accepted value of 10,000 years. In its reference to this latest interval of geologic time, Holocene is essentially synonymous with Recent and Postglacial.

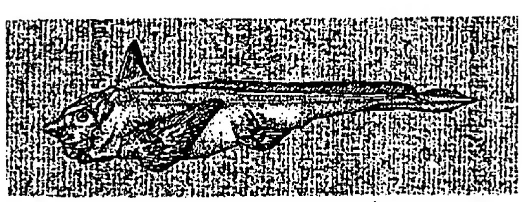
The term is applied most commonly to sediments. Holocene strata represent virtually every environment of deposition, as they include all the sediments that are being deposited at present. Modern literature employs the term quite broadly as a time indicator for many other geological phenomena, such as uplift, ocean circulation, and volcanism. This usage follows the spirit of uniformitarianism in its analysis of modern geologic phenomena and their products in order to provide comparative standards for the interpretation of ancient features for which the formative processes are not observable.

Although Holocene time falls well within the range of ^{14}C dating, it lacks an accepted value for its duration owing to the uncertainty of its inception. The term Postglacial is applied by pollen stratigraphers in northern Europe to the sediments containing pollen zones IV–IX, approximately the last 10,000 years according to ^{14}C dating. *See Pleistocene; Postglacial vegetation and climate.*

Roscoe G. Jackson, II

Holocephali

One of two Recent subclasses of the cartilaginous fishes, or Chondrichthyes. The Holocephali, or chimaeras, differ from the other subclass, the Elasmobranchii, or sharks and rays, in having only fo… of gill arches and gills that open to the exterior… a single pair of apertures; in the erectile dorsal fi… spine (see illus.); in the naked skin in adults; … the absence of a cloaca and of ribs. Males are us… equipped with a frontal clasper on the head. The… are consolidated into six pairs of plates and the… jaw is immovably fused with the brain case; the… aptations function in grinding mollusks, their… food. Chimaeras date from the early Mesozoic. … are classified into a single order, the Chimaerifo… 1 family, the Chimaeridae, 4 or 5 genera, and ab… 24 species. All chimaeras are marine, most living… deep water. They are of little economic importa… *See Chondrichthyes.*



Deepwater chimaera (*Hydrolagus affinis*), length to 3 ft (0.9 m). (*After G. B. Goode and T. H. Bean, Oceanic Ichthyology, U.S. Nat. Mus. Spec. Bull. 2, 1895*)

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Bibliography. J. Tee-Van et al. (eds.), *Fishes of the Western North Atlantic*, Sears Found. Mar. Re… Mem. 1, pt. 2, 1954.

Holography

A technique for recording, and later reconstructing, the amplitude and phase distributions of a coherent wave disturbance. Invented by Dennis Gabor in 1948, the process was originally envisioned as a possible method for improving the resolution of electron microscopes. While this original application has not proved feasible, the technique is widely used as a method for optical image formation, and in addition has been successfully used with acoustical and radio waves. This article discusses holography with electromagnetic waves in the optical and microwave regions of the electromagnetic spectrum, and its potential use with x-rays. For holography with sound waves *see Acoustical holography.*

Optical Holography

Optical holography makes use of a highly coherent beam of light, such as supplied by a laser source. *See Laser.*

Fundamentals of the technique. The technique is accomplished by recording the pattern of interference between the unknown object wave of interest and a known reference wave (Fig. 1). In general, the object wave is generated by illuminating the (possibly three-dimensional) subject of concern with the coherent light beam. The waves reflected from the object strike a light-sensitive recording medium, such as photographic film or plate. Simultaneously a portion of the light is allowed to bypass the object, and is sent directly to the recording plane, typically by means of a mirror placed next to the object. Thus incident on the recording medium is the sum of the light from the object and a mutually coherent reference wave.

While all light-sensitive recording media respond only to light intensity (that is, power), nonetheless in the pattern of interference between reference and object waves there is preserved a complete record of both the amplitude and the phase distributions of the object wave. Amplitude information is preserved as a modulation of the depth of the interference fringes, while phase information is preserved as variations of the position of the fringes. *See Interference of waves.*

The photographic recording obtained is known as a hologram (meaning a total recording); this record generally bears no resemblance to the original object, but rather is a collection of many fine fringes which

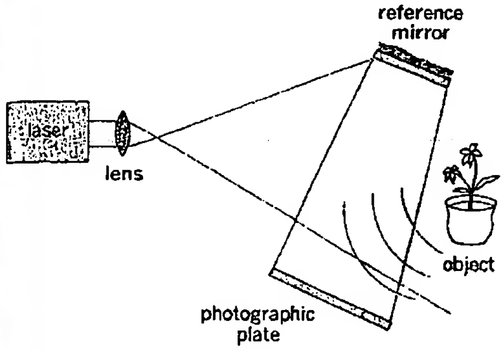

Fig. 1. Recording a hologram.

appear in rather irregular patterns (Fig. 2). Nonetheless, when this photographic transparency is illuminated by coherent light, one of the transmitted wave components is an exact duplication of the original object wave (Fig. 3). This wave component therefore appears to originate from the object (although the object has long since been removed) and accordingly generates a virtual image of it, which appears to an observer to exist in three-dimensional space behind the transparency. The image is truly three-dimensional in the sense that the observer's eyes must refocus to examine foreground and background, and indeed can "look behind" objects in the foreground simply by moving the head laterally.

Also generated are several other wave components, some of which are extraneous, but one of which focuses of its own accord to form a real image in space between the observer and the transparency. This image is generally of less utility than the virtual image because its parallax relations are opposite to those of the original object.

Applications. The holographic technique has a number of unique properties which make it of great value as a scientific tool. Although the field is young, and new applications are continually emerging, certain important areas can be identified.

Microscopy. Historically, microscopy is the potential application of holography that has motivated much of the early work, including the original work of Gabor. The use of holography for optical microscopy has been amply demonstrated, but these techniques are not serious competitors with more conventional microscopes in ordinary microscopy.

Nonetheless, there is one area in which holography offers a unique potential for optical microscopy. This area might be called high-resolution volume imagery. In conventional microscopy, high transverse resolution is achieved only at the price of a very limited depth of focus; that is, only a limited portion of the object volume can be brought into focus at one time. It is possible, of course, to explore a large volume in sequence by continuously refocusing to examine new regions of the object volume, but such an approach is often unsatisfactory, particularly if the object is a dynamic one, continuously in motion. A solution to this problem is to record a hologram of the object by using a pulsed laser. The dynamic object is then "frozen" in time, but the recording contains all information necessary to explore the full object volume with an auxiliary optical system. Sequential observation is acceptable because the object (that is, the holographic image) is no longer dynamic. This approach has been fruitfully applied to the microscopy of three-dimensional volumes of living biological specimens and to the measurement of particle-size distributions in aerosols.

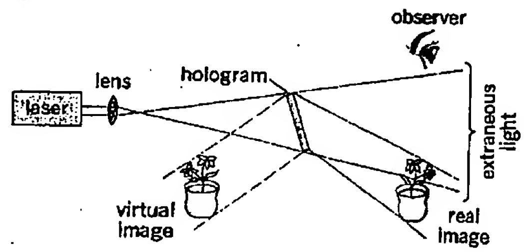

Fig. 3. Obtaining images from a hologram.

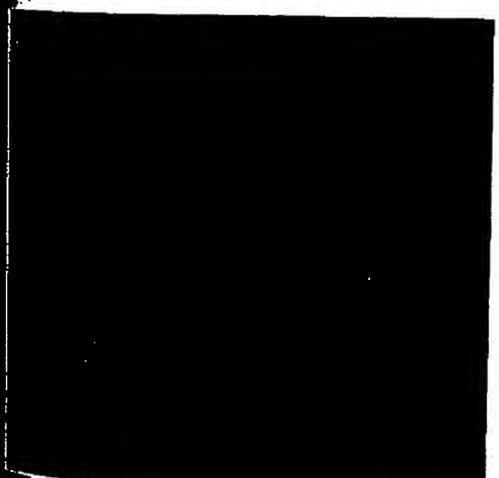

Fig. 2. Typical appearance of a hologram (under magnification).

Interferometry. Holography has been demonstrated to offer the capability of several unique kinds of interferometry. This capability is a consequence of the fact that holographic images are coherent; that is, they have well-defined amplitude and phase distributions. Any use of holography to achieve the superposition of two coherent images will result in a potential method of interferometry.

The most powerful holographic interferometry techniques are based on the following property: When a photographic emulsion is multiply exposed to form several superimposed holograms, upon reconstruction the several corresponding virtual images are formed simultaneously and therefore interfere. Likewise the various real images interfere.

The most dramatic demonstrations of this type of interferometry were performed by R. E. Brooks, L. O. Heflinger, and R. F. Wuerker, using a pulsed ruby laser. Two laser pulses were used to record two separate holograms on the same transparency. Any changes of the object between pulses resulted in well-defined fringes of the interference in the reconstructed image (Fig. 4). The technique is particularly well suited for performing interferometry through imperfect optical elements (for example, windows of poor quality), thus making possible certain kinds of interferometry that could not be achieved by any classical means. *See Interferometry.*

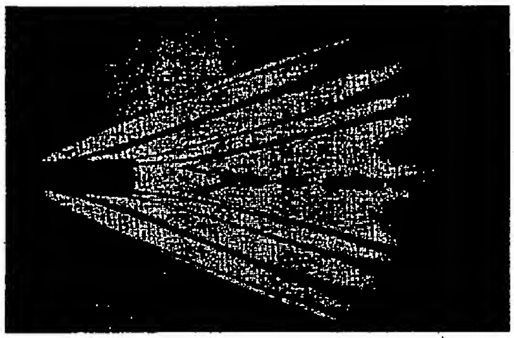

Fig. 4. Image taken by the technique of holographic interferometry, showing the compressional waves generated by a high-speed rifle bullet. *(Courtesy of R. E. Brooks, L. O. Heflinger, and R. F. Wuerker)*

Memories. Optical memories for storing large volumes of binary data in the form of holograms have been intensively studied. Such a memory consists of an array of small holograms, each capable of reconstructing a different "page" of binary data. When one of these holograms is illuminated by coherent light, it generates a real image consisting of an array of bright or dark spots, each spot representing a binary digit. This image falls on a detector array, with one detector element for each binary digit. Thus to read a single binary digit at a specific location in the memory, a beam deflector causes light to illuminate the appropriate hologram page, and the output of the proper detector element is interrogated to determine whether a bright spot of light exists at that particular location in the image.

In spite of several identifiable advantages of holographic memories over other methods of optical storage, the holographic technique is not regarded as a viable commercial alternative to bit-by-bit optical storage in ablative media, as practiced, for example, with digital audio disks. *See Computer storage technology; Disk recording.*

Display. There has been interest in the use of holography for purposes of display of three-dimensional images. Applications have been found in the field of advertising, and there is increased use of holography as a medium for artistic expression. A significant technical development in this area has been the perfection of a type of recording known as a multiplex hologram. Such a recording typically consists of a large number of separate holograms, all in the form of thin, contiguous, vertical strips on a single piece of film. Each of these holograms produces a virtual image of a different ordinary photograph of the subject of interest. In turn, each such photograph was originally taken from a slightly different angle. Thus when the observer examines the virtual image produced by the entire set of holograms, each eye looks through a different hologram and sees the subject from a different angle. The resulting stereo effect produces a nearly perfect illusion of three-dimensionality. Furthermore, as an observer moves the head horizontally, or as the collection of holograms is rotated, the observer's two eyes continuously see a changing pair of images. If the original set of photographs is properly chosen, the image can be made to move or dance about in nearly any desired fashion. Very dramatic three-dimensional displays of animated subjects can thus be constructed from a series of ordinary photographs. Such displays do not require a laser for viewing, but rather can be utilized with white-light sources.

Holographic optical elements. A hologram consisting of the interference of a plane reference wave and a diverging spherical wave, upon illumination by a reconstruction plane wave, will generate a diverging spherical wave (the virtual image) and a converging spherical wave (the real image), each traveling in a different angular direction. Thus such a hologram behaves as an optical focusing element, with properties similar to those of a lens (or, more accurately, a pair of lenses). More complex holograms can generate a multitude of foci, in virtually any pattern desired. Alternatively, by varying the periodicity of the grating-like structure of the hologram, a small laser beam can be deflected through an angle that is controlled by the local period of the structure. Holograms which are used to control transmitted light beams, rather than to display images, are called holographic optical elements. Interest in such elements has grown substantially, and commercial applications have been found. Most notable is the use of holograms in supermarket scanners at check-out stands. Light from a helium-neon laser falls on a small region of a holographic optical element, which was recorded on a disk and is rotating continuously. As the hologram rotates, different portions of the hologram containing different grating periods are illuminated, and the angle of deflection of the laser beam sweeps through a pattern that was predetermined when the hologram was recorded. In this way the laser beam is caused to follow a complicated scan pattern, which ultimately allows the reading of information from the bar-code patterns recorded on each product. *See Character recognition; Geometrical optics; Optical image.*

Other applications. A variety of other applications of holography has been proposed and demonstrated, including the analysis of modes of vibration of complicated objects, measurement of strain of objects under stress, generation of very precise depth contours on three-dimensional objects, and high-resolution imagery through aberrating media. These and other applications of holography will be useful in future scientific and engineering problems. *Joseph W. Goodman*

Microwave Holography

Microwave holography is microwave imaging by means of coherent continuous-wave electromagnetic radiation in the wavelength range from 1 mm to 1 m. As a long-wavelength imaging modality, it differs from techniques which employ echo timing (for example, conventional radar) by its requirement for phase information. In this respect it resembles optical holography, from which it has departed significantly. The technique usually involves small-scale systems, that is, systems in which the effective data acquisition aperture is of the order of tens or hundreds of wavelengths. Microwave holographic imaging is characterized by high lateral-resolution capability in comparison with images obtained from echo timing. The natural image format of the data it presents to the human observer enhances its diagnostic potential. In particular, it conveniently produces phase imagery which increases further its diagnostic capability. *See Microwave; Radar.*

Microwave holographic imaging originated from the two-stage optical process consisting of data recording in the form of an interferogram, and image reconstitution (from a transparency reduced in size

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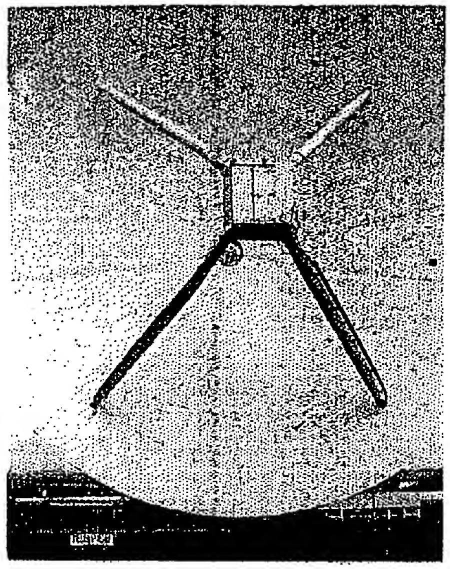

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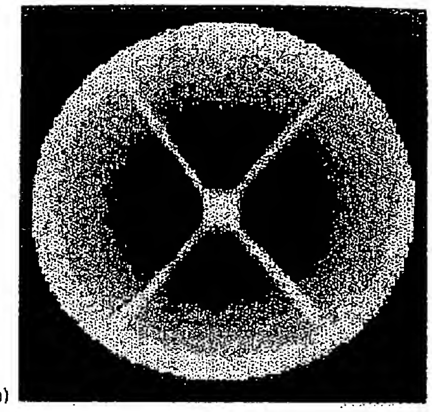
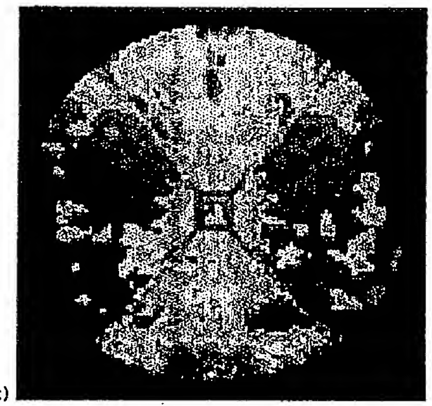


(b)

Applications of microwave holographic imaging. (*a*) 82-ft-diameter (25-m) paraboloidal reflector antenna structure used in satellite communications. (*b*) Conventional image of the antenna obtained by using a false-color display to quantify the amplitude distribution over the reflector of microwave radiation from a ground-based source. (*c*) Phase image of the antenna, showing deviations from an ideal paraboloid. (*d*) Microwave image of two subsurface pipes in the form of a cross, one metal and one plastic. (*e*) Test object made from a microwave-penetrable material and (*f*) measurement obtained from its microwave holographic phase tomogram or slice.



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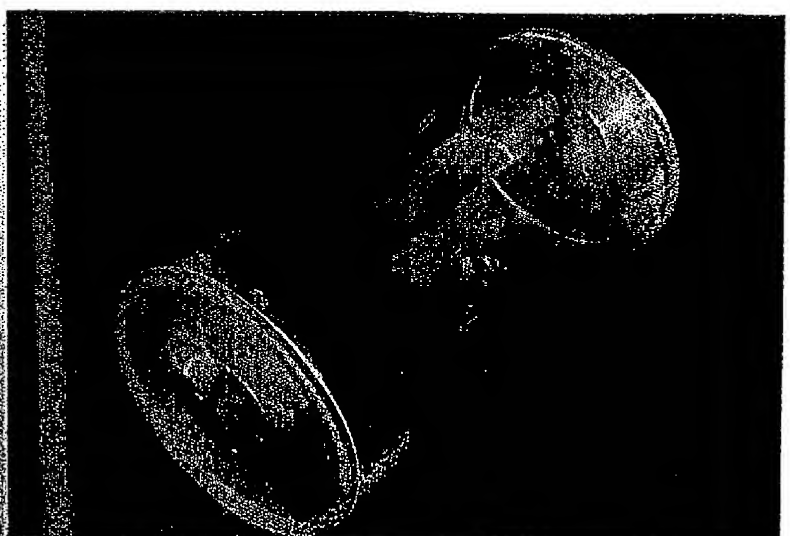

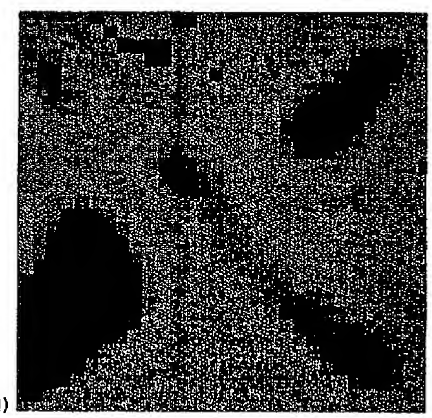

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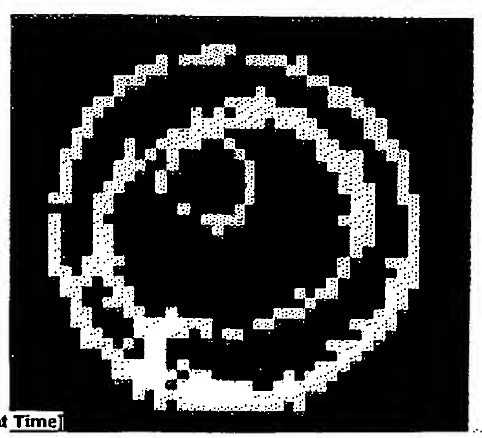

because of the larger wavelength) by optical diffraction. The first microwave (and acoustic) holograms were recorded in 1951 before the availability of lasers. The first publicized demonstration of small-scale microwave imaging occurred in 1965 (Fig. 5). The object was a metal letter A with a height of approximately 7 ft (2 m), that is, 70 wavelengths, illuminated by X-band microwave radiation with a wavelength of approximately 30 mm. The hologram (approximately 10 × 10 ft or 3 × 3 m) was mapped by recording the field intensity and converting it to a small transparency for image construction by laser light. Subsequently the methods of data recording and the replacement of the optical diffraction process by digital computation transformed microwave holography into a diagnostic imaging technique in its own right.

Data recording. The replacement of the optical diffraction process by computer processing using a fast Fourier transform algorithm has important implications for the data-recording stage. Instead of obtaining the microwave interferogram analogously to the optical process, the microwave field scattered by the object is recorded directly in amplitude and phase by using a microwave receiver which compares the measured field at any point in space with a reference value. For the forward-scatter case (Fig. 6*a*), the object (which may be semitransparent to microwaves) is illuminated from a microwave source and transmitting antenna T_x. A receiving antenna scans through known coordinates in the surface S and feeds the field values at each point to the receiver. Since a portion of the source energy is fed directly to the receiver by a separate reference channel (either a free space path or a waveguide), the receiver can generate the complex field values (phase and amplitude) at each point. An alternative recording geometry, the backscatter mode (Fig. 6*b*) is the usual configuration for radar systems. The transmitting and receiving antennas are either the same antenna or two antennas close together, as

Fig. 5. Optically reconstructed image using laser light (wavelength equal to 0.6328 μm) of metal letter A 70 wavelengths high at the X band (wavelength of approximately 30 mm). (*From R. P. Dooley, X-band holography, Proc. IEEE., 53:1733–1755, 1965*)

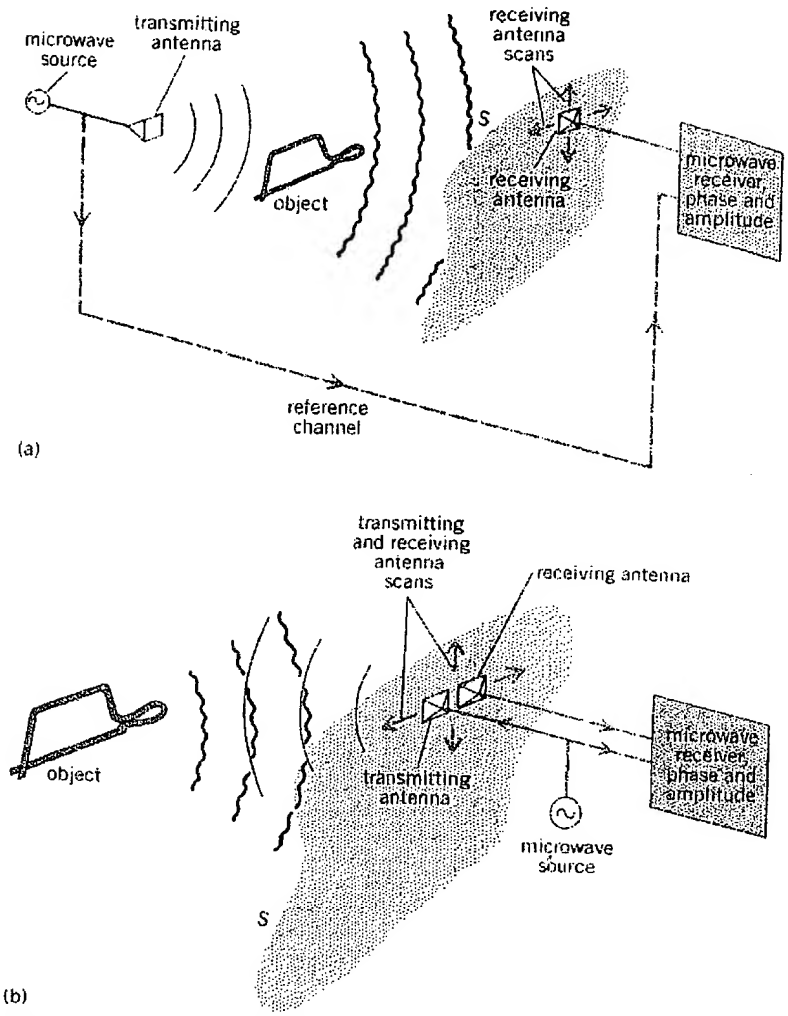

Fig. 6. Typical scan geometries for recording complex field data. (a) Forward-scatter mode. (b) Backscatter mode.

shown. The antennas scan as a unit over the desired surface S, and the complex field values are recorded. Because the illumination from the transmitting antenna also scans the object in this case, the resolution of the system is doubled in comparison with the forward-scatter case.

Computer processing. The sampled field values recorded over the surface S may be expressed as an array of complex numbers and are therefore suitable for computer processing. The computer algorithm is designed to reconstitute an image from the particular scan geometry used. The process can be thought of as effectively inverting the propagation process that brought the scattered waves to the surface S. The inversion process usually incorporates a version of the fast Fourier transform algorithm to convert the data recorded on S (not strictly a hologram) into the reconstructed object. The computer transfers its output to a memory and then a television monitor display. The important advantages of this digital microwave holographic process are (1) the availability of numerical field values with high accuracy and low noise; (2) the separate operations on the phase and amplitude values, and the separate display of these values; (3) the

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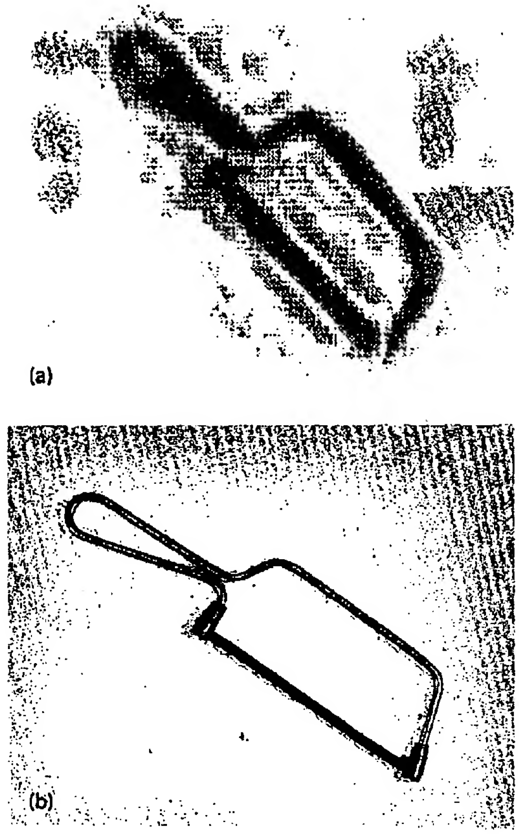

Fig. 7. Comparison of (a) digitally reconstructed microwave image of object 20 wavelengths long at the Q band (wavelength of 9 mm), showing reflections from surroundings, with (b) optical photograph of object.

possibility of computer-observer interaction at any stage of the processing; and (4) the options of monochrome or false color display format. *See* HARMONIC ANALYZER.

Imaging applications. The efficacy of microwave holography as an imaging modality independent of optical holography is evidenced by a comparison of the microwave image of an object (Fig. 7*a*) with the optical photograph (Fig. 7*b*). The object is only 20 wavelengths long at the microwave frequency, and yet considerable resolution of detail is observed. However, the role of microwave holography is not to mimic optical holography. Until 1979, perhaps the most useful diagnostic application of microwave holographic imaging was the metrology of large reflector antennas. The data acquisition procedure is a variant of that in Fig. 6*a* since the object itself is scanned in both azimuth and elevation to synthesize the holographic aperture. In this arrangement (Fig. 8*a*), the test antenna itself feeds the complex field values to the microwave receiver, and so functions simultaneously as the receiving antenna and the object. The transmitting antenna is located either on the ground, in the near field of the test antenna, or on board a synchronous satellite. The image, that is, the conventional notion of an image (Fig. 8*b*), is obtained by quantifying the amplitude distribution over the reflector, and also shows the support legs and the focal region "laboratory." More important is the phase image (Fig. 8*c*), which corresponds to the errors in the reflector profile, that is, deviations from the ideal paraboloidal shape. Other important diagnostic information can be derived, for example, the astigmatism due to gravitational distortion which is apparent in Fig. 8*d*.

Microwave holography is also useful in applications where images of concealed structure are required. Microwave radiation penetrates a variety of dielectric media to a depth depending on the attenuation of a given wavelength in a particular medium. One such application is the mapping of subsurface pipes and cables. A scanning arrangement for this purpose (Fig. 9*a*) uses the backscatter mode of Fig. 6*b*. The detection of the backscatter from the buried pipes, which is very weak after suffering attenuation in the soil, is assisted by the polarization discrimination of the receiving antenna. The data acquisition and computer processing follow the normal procedure with compensation for microwave propagation in the soil. The image in Fig. 9*b* shows two pipes in the form of a cross, one of them a metal pipe and the other a plastic pipe. Hence this noninvasive microwave technique has a diagnostic power greater than the normal metal detectors. *See* NONDESTRUCTIVE TESTING.

Microwave tomography. The major limitation of the microwave holographic techniques discussed

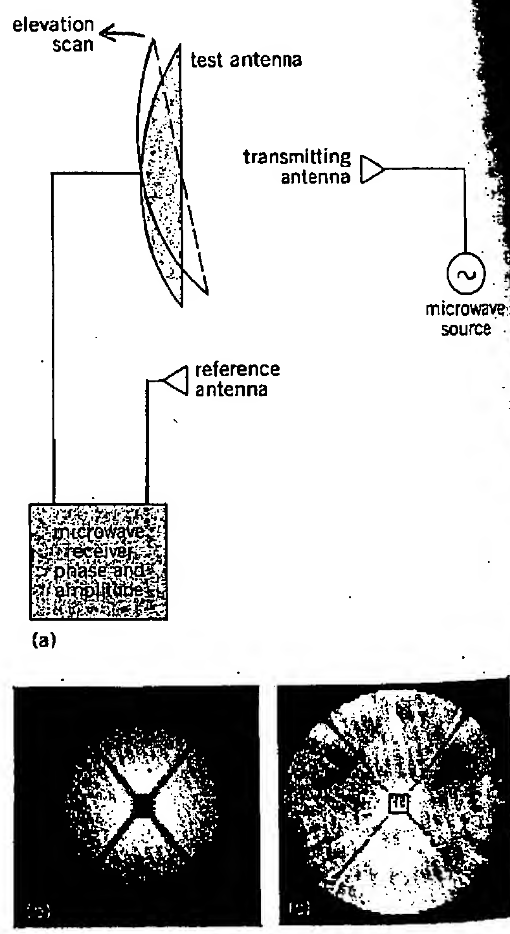

Fig. 8. Applications of microwave holographic imaging to metrology of an 82-ft-diameter (25-m) paraboloidal reflector antenna structure used in satellite communications. (a) Scan geometry used for data recording. (b) Amplitude image showing aperture illumination distribution. (c) Phase image showing deviations from the ideal paraboloid.

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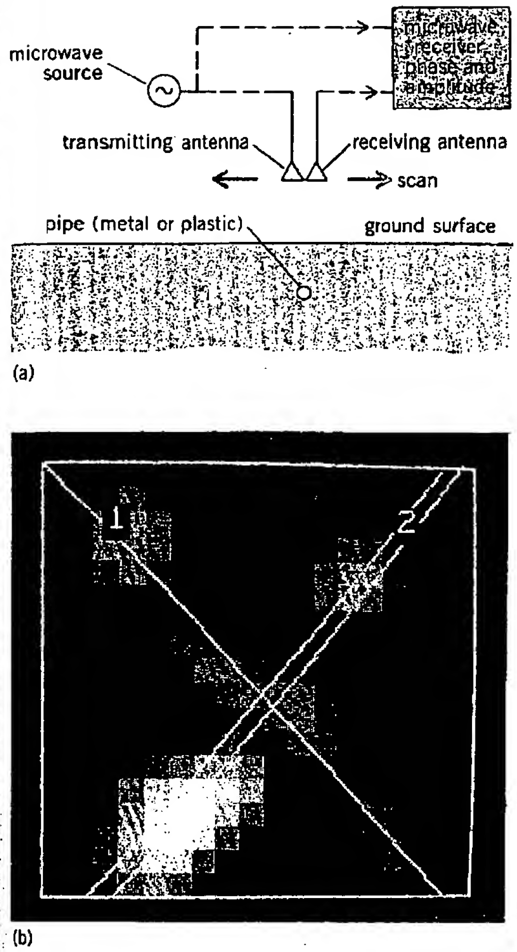

Fig. 9. Subsurface imaging. (a) Scan system. (b) Microwave amplitude image, at wavelength of 0.6 m (2 ft), of two crossed pipes whose positions are indicated by solid lines. Pipe 1 is plastic; pipe 2 is metal. Field of view is 7 × 7 ft (2 × 2 m).

above is that the images produced are essentially two-dimensional. This may seem surprising, given the fact that optical holography is a three-dimensional image construction process. The reason is that the microwave wavelength is so long (10^4–10^6 times that of light) that the depth of focus of the microwave hologram is prohibitive. This disadvantage is overcome by employing a tomographic mode of imaging which exploits the ability of microwaves to penetrate many materials and thereby characterize their three-dimensional structure more accurately. This development is analogous to the technique of computer-aided tomography used in x-ray scanning systems. Microwave holographic tomography requires holograms to be recorded from different views of the object and synthesized. Again, the availability of phase imagery increases its diagnostic potential. *See Computerized tomography.*

Alan P. Anderson

X-Ray Holography

Physicists and life scientists have been engaged in research that will ultimately allow three-dimensional imaging of living organisms with resolution and contrast far beyond the reach of optical microscopes. The impetus for this activity is the imminent availability of high-intensity coherent sources of electromagnetic radiation with wavelengths between 0.1 and 10 nanometers. Much of the study is concentrated on holographic imaging because it can eliminate the need for focusing elements which are difficult to fabricate with enough precision to achieve diffraction-limited resolution in the soft x-ray regime. Furthermore, several of these new sources promise extremely high intensity and subnanosecond pulses, and can circumvent the problem of killing and altering the specimen with the x-ray exposure by extracting an image from the specimen before it is obliterated. *See X-ray optics; X-rays.*

X-ray sources. To be suitable for holography, the x-radiation must be monochromatic and have a relatively high degree of coherence. Synchrotrons using magnetic undulators can generate a narrow band of intense radiation. Use of monochrometers and pinhole apertures can improve the coherence of this radiation at the sacrifice of intensity but with retention of sufficient intensity to image biological specimens on time scales from a few seconds to a few hours. *See Synchrotron radiation.*

There are several promising sources. Nonlinear optical frequency multiplication techniques produce intense picosecond pulses of tunable coherent radiation, and have reached wavelengths as short as 40 nm. Similarly, multiphoton excitation can pump atoms to higher energy levels that have lasing transitions at wavelengths much shorter than the excitor laser. X-ray lasers driven by nuclear explosives and by more conventional laboratory sources are under development. X-ray and gamma-ray lasers will be inherently short-pulse, high-intensity devices because they will probably not have resonant cavities, so the radiation being amplified can make only a single passage through the active medium; and the creation and maintenance of a high density of excited atomic states of short lifetime and high quantum energy require enormous power, which terrestrial sources can supply only in the form of pulses. *See Nonlinear optics.*

Geometries. Essential features of the principal geometries for holography are shown in Fig. 10. The Fresnel transform techniques use planar reference waves and have resolution limited by the grain size of the recording medium. The on-axis (Gabor) form is inherently simple but suffers from overlap of the real and virtual images. The off-axis (Leith-Upatnieks) modification reduces the image overlap problem but requires a mirror and a broadened beam for system illumination; both forms may be difficult at x-ray wavelengths. The Fourier transform (Stroke) geometries, using curved wavefronts, achieve large fringe spacings and are therefore less sensitive to grain size.

Coherence is characterized by the effective finite length of a photon wave train in the transverse direction (spatial). Both coherence length and geometry limit the holographable volume of a specimen. For most specimens of biological interest, spatial and temporal coherence lengths of 10 micrometers to 1 nm are adequate.

Interactions of x-radiation. The interaction of x-radiation with matter is quite different from the interaction of visible light with matter. Whereas the extinction of a visible beam traversing matter is mainly due to scattering, the extinction of an x-ray beam is

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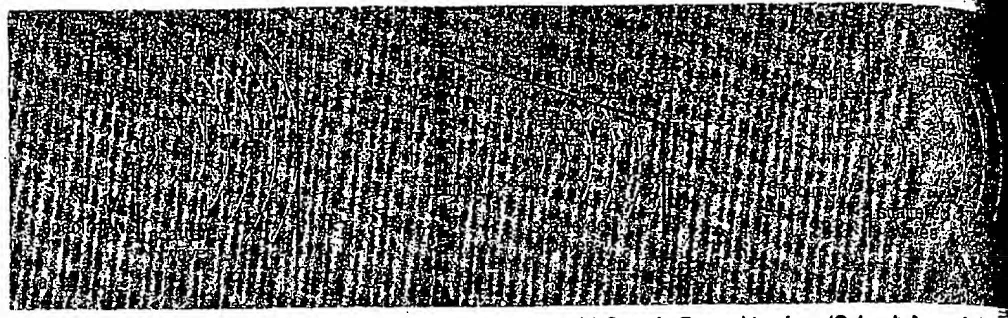

Fig. 10. Geometric configurations of x-ray holographic techniques. (a) On-axis Fresnel tranform (Gabor holography). (b) Off-axis Fresnel transform (Leith-Upatnieks holography). (c) Planar Fourier transform (Stroke holography).

mainly due to absorption. X-rays can also be scattered, but usually the cross section for coherent scattering is very much smaller than for absorption. In the visible regime, holographic images are primarily formed by refraction or reflection, whereas in the x-ray regime they are dominated by diffraction. The greatest contrast in x-ray absorption between water, which composes most of the cytoplasm, and protein (or the nucleic acids) occurs between the K edges of oxygen and nitrogen.

Snapshot x-ray holography. Existing x-ray sources, in particular, synchrotron radiation sources, have been used to make holograms. However, they require long exposures, limiting their usefulness for research on living specimens. More coherent sources may also be developed, but those of low intensity will be similarly limited, since ionization will have decomposed molecules, modified compositions, and altered biological functions before enough radiation can be received to form a useful hologram. Snapshots are essential for x-ray holography of living specimens. Fortunately, it is likely that x-ray sources producing brief intense bursts will be developed.

With an intense pulsed coherent source (such as an x-ray laser), hydrodynamic expansion, initiated by sudden heating, rather than normal biological activity, chemical change, or thermal agitation, will limit the time during which recording of the hologram must be accomplished. Analytical expressions for the explosion of a semiopaque feature (such as a protein globule) are useful for estimating the radiation requirements for typical cases. They are based on the criterion that, to achieve a linear resolution δ, a specified minimum number of photons must have been coherently scattered in a volume δ^3 and that, during the exposure time Δt, no dimension of the specimen should have increased by more than δ. For most biological specimens, intensities on the order of 10^{12} W $\cdot$ cm^{-2} with pulse lengths on the order of 10^{-11} s will be required to obtain an x-ray hologram with resolution of 10 nm.

Recording. An x-ray hologram can be registered by radiation-induced prompt or latent chemical change, or by photoelectron emission. Photographic emulsion is unsatisfactory for Fresnel transform x-ray holography because the resolution is limited by grain size. If an electron microscope could be used to image the points of electron emission from a photocathode reference surface, time-gated holography might be possible. However, the continuous distributions in energy and in angles of emission of electrons from a photocathode preclude the formation of sharp electron-optical images, imposing a trade-off between quantum efficiency and resolution, unless image-deblurring analysis can be applied. Photoresists (materials that lose resistance to chemical etching at points exposed to radiation) have grain sizes that approach 5 nm, which is entirely adequate for x-ray holograms with resolutions of 10 nm. To reconstruct a photoresist hologram, a transmission electron micrograph could be formed and viewed with visible laser illumination, or a transmission electron microscope could be used to scan and digitize the photoresist for analysis by computation, which can also mitigate nonlinearities that may be troublesome in optical reconstruction. SEE ELECTRON MICROSCOPE; PHOTOEMISSION; PHOTOGRAPHIC MATERIALS.

By using Fourier transform x-ray holography, it is possible to arbitrarily adjust the fringe spacing at the sacrifice of intensity and thereby record with common photographic emulsions. However, when compared with photoresists on the basis of number of quanta required to produce a developable speck, it is not clear that the greater sensitivity of photographic emulsions offers any advantage, and consequently there is no clear advantage of Fourier over Fresnel methods.

Practical considerations. The realization of x-ray holography as a practical research tool still awaits the solution of some challenging technical problems:

1. Development of sources that can generate intense coherent radiation at the precise wavelengths to optimize contrast among specimen constituents. Perhaps nonlinear mixing with tunable visible radiation will be necessary.

2. Termination of exposure within a sufficiently brief time interval and with sufficient intensity to achieve the desired resolution, as discussed above. Frequency multiplication techniques and multiphoton excitation lasers can achieve these short pulses because the optical laser driving them can be mode-locked. Corresponding schemes are difficult to envisage for x-ray or gamma-ray lasers, and their pulse lengths are likely to be much longer. A shutter or gate, somewhere in the system, that operates when full intensity is reached will be essential. SEE OPTICAL PULSES.

3. In principle, photoelectric recording could be time-gated. However, complexity and precision required of the electronics, and blurring associated with initial electron velocity distribution make this approach unattractive. On the other hand, exposure control in photoresist recording is not likely to be managed by a gate; therefore exposure control must be provided elsewhere in the system.

4. Leith-Upatnieks holography may be necessary to avoid image overlap obscuration, and this requires

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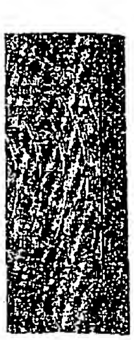

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an x-ray mirror. A synthetic Bragg crystal may suffice, and thermal expansion, if sufficiently uniform, can provide automatically time-gated reflection.

Johndale C. Solem

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Holostei

One of three organizational levels (infraclasses) of the subclass Actinopterygii, or rayfin fishes. The holosteans are descended from the older Chondrostei and in turn are ancestral to the great mass of modern bony fishes, the Teleostei. It is not certain whether holosteans evolved from a single stock or multiple stocks of the Chondrostei. SEE CHONDROSTEI; TELEOSTEI.

Phylogeny. Holosteans made their first appearance in the Upper Permian as the order Semionotiformes; three additional orders arose in the Triassic Period, and the fifth and last order, the Aspidorhynchiformes, evolved in the Middle Jurassic. In the Jurassic and Lower Cretaceous, holosteans dominated actinopterygian fish life, but by the Late Cretaceous they had been largely replaced by teleosts. The specialized Pycnodontiformes persisted until the Eocene, but the spindle-shaped, predacious Aspidorhynchiformes and the Pholidophoriformes, which are likely ancestors of the Teleostei, died out in the Cretaceous. Fragmentary remnants of two large orders persist to the present time as survivors of the Mesozoic: Semionotiformes, as the North American and Middle American gars (family Lepisosteidae), and Amiiformes, as a single species, the bowfin (family Amiidae) of eastern North America. Understandably, both groups have been intensively studied by biologists in search of clues to the life of the past.

Morphology. Holosteans, although highly varied in body form, were structurally as well as temporally intermediate between chondrosteans and teleosts, to which group they passed on substantial advances. Mouthparts were improved by horizontal suspension of the hyomandibular from the skull, a more forward positioning of the angle of the gape, and the development of a strong coronoid process on the mandible. The maxilla was freed posteriorly, and the entire feeding mechanism became more mobile and was strengthened, thus permitting diversification in food habits, though most holosteans were predacious. The caudal fin is typically abbreviate heterocercal, with the posterior vertebrae upturned but not forming a long upper lobe. Typically the anterior upturned centra each support a single, slender hypural. Dorsal and anal fin rays are strengthened and reduced in number to approximate serial equivalence with the internal supports. In early forms scales are often thick and rhomboidal, as in chondrosteans, but in certain advanced types are thin and rounded; they retain an enamellike outer layer (ganoine) that is lost in all but the earliest teleosts. In living holosteans the swim bladder is highly vascularized, and auxiliary aerial respiration is possible, a sometimes essential faculty in oxygen-poor waters of swamps. SEE ACTINOPTERYGII; AMIIFORMES; ASPIDORHYNCHIFORMES; PHOLIDOPHORIFORMES; PYCNODONTIFORMES; SEMIONOTIFORMES.

Reeve M. Bailey

Holothuroidea

A class of Echinozoa characterized by a cylindrical body and smooth leathery skin, and known as sea cucumbers. There are no arms, but a ring of five or more tentacles may surround the mouth, which is usually at one end of the body. There are no pedicellariae. Tube feet may be present or lacking. There are no ambulacral grooves, although they are represented by internal epineural canals overlying the radial nerves. E. Deichmann (1957) regards them as the most aberrant group of extant echinoderms. SEE ECHINOZOA.

Holothurians resemble worms because the pentamerous symmetry is largely concealed by a secondary bilateral symmetry, and the general absence of external spines distinguishes them from the other extant echinoderms. They tend to rest on one side, so that the axis of radial symmetry becomes horizontal. This habit leads to the differentiation of an upper (dorsal) surface and a lower (ventral) one. The dorsal side corresponds to the interradius which contains the madreporite, and therefore the ventral side is one of the radii. Each radius runs from the anterior to the posterior end. If tube feet are developed, their disposition indicates the radii (Fig. 1).

The 1100 living species have been grouped in 170 genera arranged in six orders: the Dendrochirotida, Dactylochirotida, Aspidochirotida, Elasipodida, Molpadida, and Apodida. Species range in size from 1.2-

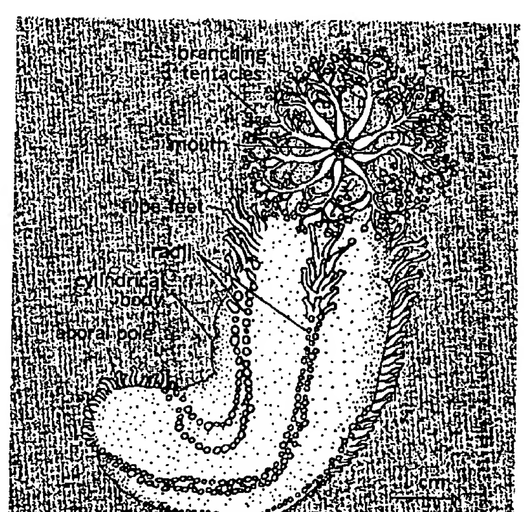

Fig. 1. *Cucumaria*, a representative holothurian.

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